MAXIMIZING ENERGY EFFICIENCY IN THE PROCESS INDUSTRIES USING PINCH ANALYSIS

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ABSTRACT

Efforts to increase plant energy efficiency have intensified with the recent increase in fuel price and the global concern on environmental emissions. As new processes and technologies emerge, existing processes are under pressure to increase efficiency and to maintain profitability in order to remain competitive. Many existing installations have focused on energy efficiency upgrading in order to increase profitability. Energy efficiency measures employed in the local industries are generally confined to the employment of good housekeeping techniques and the upgrading of utility systems (i.e. boilers, steam systems, chillers, hot oil circuit, refrigeration and cooling systems). Very few companies are willing to venture deep into process operations to further reduce energy consumption. As a result, benefits that can be derived from a retrofit project can be very limited. The advent of Pinch Technology provides a comprehensive as well as systematic approach to maximise a plant's energy efficiency. This paper briefly reviews the key principles of Pinch Technology and highlights the results of Pinch Analysis studies conducted on the local industries to maximize the energy efficiency.

Keywords: *Pinch Technology, Composite Curves, Grand Composite Curves, Retrofit, Utility Systems.*

REVIEW OF THE BASIC PINCH PRINCIPLES

Pinch applications begin with a simple plot of process hot and cold streams enthalpy aggregate on a temperature vs. enthalpy diagram (shown in Fig. 1). The pair of "composite curves", provide profound insight for the design and retrofit of thermodynamically efficient systems. In essence, the curves give an overall picture of the process streams heat availability and requirement. The shaded region on the curves indicates the maximum possible heat recovery between the process streams. The overshoots of both hot and cold curves represent the minimum hot and cold utility requirements or the energy targets for the process. The point of closest approach between the hot and cold composites is referred to as the "pinch" which limits the process heat recovery. The pinch divides the process into two thermodynamically *separate systems*, each of which is in enthalpy balance with its relevant utility. It follows that the hot and cold utilities are the *only* required utilities for the process *above* and *below* the pinch respectively. In order to avoid excess utility consumption, the following rules must be observed at all times.

1. Keep the systems above and below the pinch independent from one another. Never allow heat to be transferred across the pinch.
2. Below the pinch, only cold utility is needed. Therefore, hot utility is irrelevant.
3. Above the pinch, only hot utility is needed. Therefore, cold utility is irrelevant.

The composite curves have proved useful in representing overall process streams heat quality and quantity, assessing the pinch situations and generating the energy targets. However, they give no clear indication of the appropriate utility level(s) especially in cases involving multiple utilities. For this purpose, knowledge of the different levels of process sources and sinks is needed.

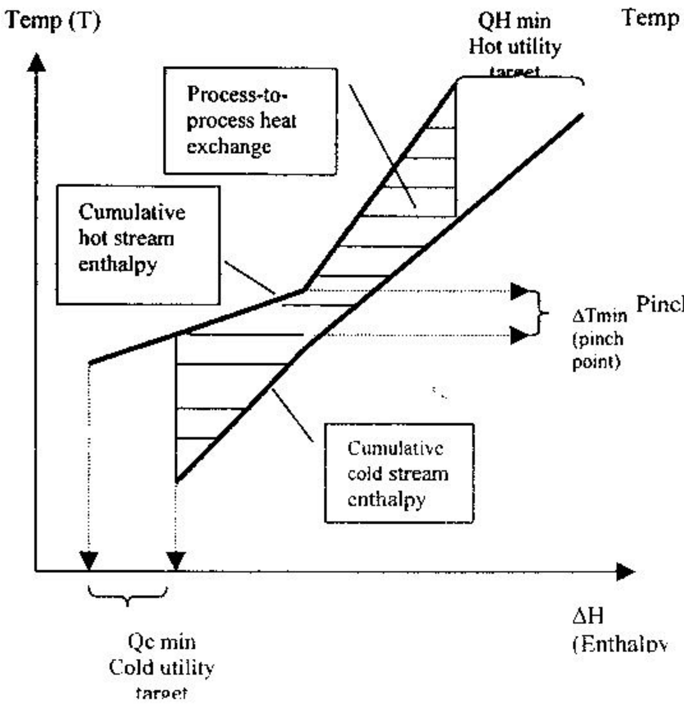


Figure 1 - Composite curves, which represent cumulative hot & cold streams enthalpy, are used to identify pinch and utility targets.

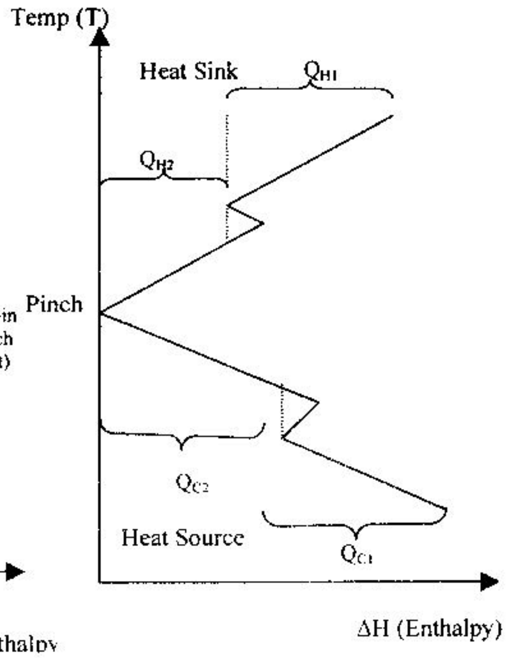


Figure 2 - Grand composite curves identify the best utility mix.

The grand composite curves shown in figure 2 is a profile of the process sources and sinks. It is generated by plotting the horizontal (enthalpy) separation between the composite curves with built in ΔTmin. Using the grand composite curves as a tool, a designer is able to select the most appropriate utility or utility mix for a process. Optimum interface between process and utility systems can now be conveniently generated.

IDENTIFYING LOSSES THROUGH ANALYSIS OF PROCESS FLOW PARAMETERS

Three common types of heat exchangers network inefficiencies may occur in existing plants. These may be due to

- Hot utility supplied to the lower temperature part of a process (heating below the pinch)
- Cold utility supplied to the higher temperature part of a process (cooling above the pinch).
- Process to process heat exchange mismatch (cross-pinch heat transfer).

Figure 3 to 4 represent a section of a palm oil refinery to be retrofitted. Careful observation of the stream conditions reveal the first two types of losses occurring in the section. In the first case (shown in Fig. 3), steam is supplied to the lower temperature part of the process while in the second (Fig.4), heat is rejected from the higher temperature part of the process directly to cooling water.

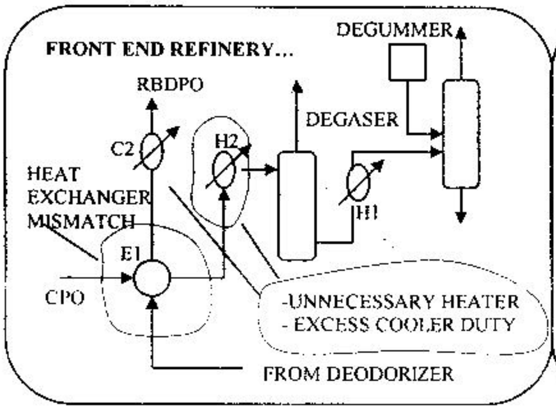


Figure 3: Heating below the pinch & cross-pinch heat transfer

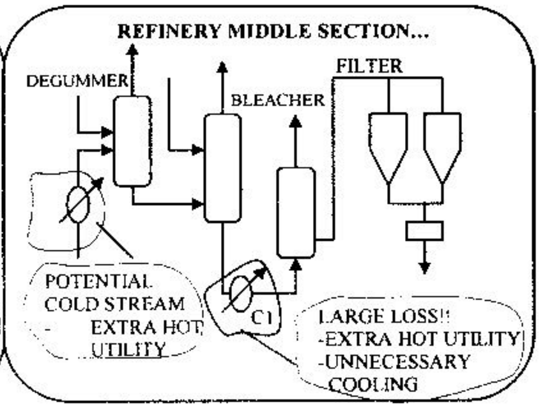


Figure 4: Cooling above the pinch.

Process to process heat exchange should replace external heating and cooling in order to reduce the operating cost. Detailed heat exchanger network retrofit has to be performed to ascertain the amount of utility savings possible.

Another type of loss may occur as a result of heat exchange mismatch between hot and cold process streams (shown in Fig. 3). The type of loss which is normally less obvious than the first two category of losses is referred to as "cross-pinch heat transfer". Larger plants with many process streams tend to exhibit such inefficiency. Pinch retrofit procedures (Tjan Joe, 1986) enable the cross-pinch matches to be detected and corrected to eliminate extra utility consumption.

HEAT EXCHANGER NETWORK (HEN) RETROFIT

The prime objective of heat exchanger network retrofit is to save energy by making better use of the existing network area. Any necessary modifications and investment needed to be kept to a minimum. Consider the tradeoff between heat exchanger network area and minimum utility target as represented by the area vs. energy plot of Fig. 5. Each data point on the curve corresponds to a unique ΔTmin (minimum approach temperature). Point A has a higher area, lower utility requirement and smaller ΔTmin compared to point C. Point B represents a tradeoff between capital and energy, giving the lowest total cost at an optimum ΔTmin. It is not possible for any design to lie in the region underneath the curve which is a locus of minimum area and energy target.

Typically, a retrofit candidate is located above the curve, say point Y. For the amount of area installed, energy is in excess by AE because of poor area utilization. The ideal retrofit moves from point Y to point A horizontally to reduce the energy excess using at least the same amount of area invested in the past. In practice however, some additional area investment is necessary to rectify the problem. This leads to a retrofit "path" which constitutes of a locus of energy reductions versus additional area as illustrated in Fig. 5. A relationship between energy savings versus investment shown in Figure 5 can be established from the best retrofit "path". Given payback criteria which is normally based on a company's policy, the investment limit and the savings generated can be defined. The information is used to determine the retrofit target in terms of ΔTmin. Next, the current network is diagnosed for pinch violations and revamped according to pinch design rules. Modifications may include heat exchanger rerouting and addition of heat transfer area (Tjan Joe, 1986).

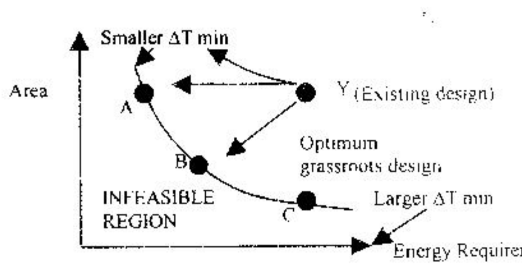


Figure 5 - Retrofit strategy to point B is impractical as this eliminate the existing heat exchange areas that have already been paid for (Tjan Tjoe, et. al)

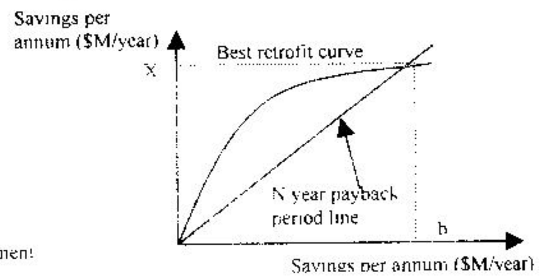


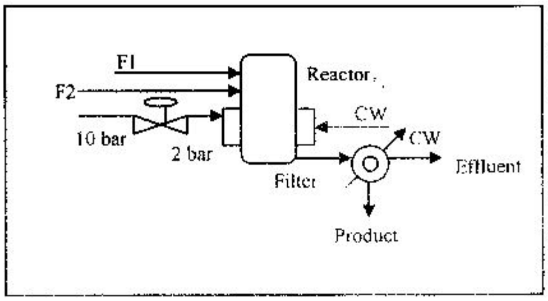
Figure 6 An investment of $ b M yields energy savings worth of $ x M/year, based on the required payback period of n year

UTILITY SYSTEMS RETROFIT

Utility systems are designed based on the heating and cooling needs of a plant. These needs depend on how well unit operations like reactors, separators and heat recovery networks are designed. Optimum unit operation designs will produce lower energy requirement. The best way to improve an existing plant's utility system is to start at the "root" of the problem. This may involve optimisations of reactor and separator conditions followed by retrofit of heat exchanger network. By doing so, the true energy needs of the plant shall be established.

The next step is to assess if a given utility is appropriately matched against the process. This is done with the aid of process grand composite curves as illustrated in the introductory section. Due to the changes made to the process, part of the utility loads may be reduced. It may also be possible to supply the utilities at lower pressures (in the case of steam) or higher temperatures (in the case of refrigerant) in order to save cost. Opportunities for combined heat and power or power generation should be considered if the new steam pressures required is much lower than in the case before retrofit. On the other hand, power consumption can be reduced if the use of low temperature refrigerant can be minimised or avoided.

There exist cases where utilities are employed at qualities significantly higher than what is required by the plant. Steam supplied at a pressure higher than utilization pressure is normally throttled down to the desired pressure. Figure 7(a) shows a section of a specialty chemical manufacturing plant (Smith and Petela, 1990). The reactor requires only 2 bar steam pressure for heating. The steam supply pressure is at 10 bar. It is throttled all the way down to 2 bar to meet the heating requirement of the reactor. There is a need to increase product recovery in the plant. In order to take advantage of the medium pressure steam available, an evaporator has been considered for the task. The final scheme is shown in figure 7(b). The scheme manage to increase product recovery and prevent "throttling losses". Energy cost has not increased. Instead, raw materials and effluent treatment costs has been reduced.



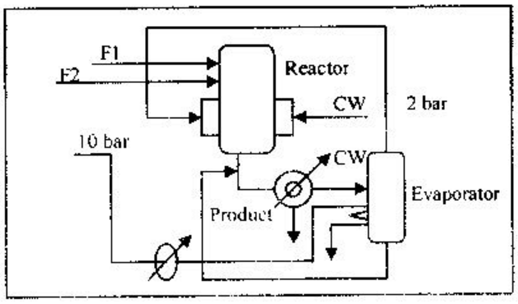


Figure 7 (a) and (b): A specialty chemical process before and after retrofit (Smith & Petela, 1990)

PROCESS MODIFICATIONS

The minimum energy targets generated from enthalpy aggregate of the process streams (as described in the introductory section) are based on fixed unit operations' conditions. It is possible to reduce the energy targets by optimising the unit operations' parameters. For reactors and separators, the possible changes include reactor conversions and recycle flowrates, distillation reflux ratios, column pressures, addition of or changes to inter-coolers/inter-reboilers and column feed preheat.

Opportunity for process changes can be conveniently identified and systematically performed using the process grand composite curves as illustrated by the following example.The grand composite curves (GRCC) of figure 8(a) and (b) represent the high temperature part of a process heated by a furnace flue gas stream (Smith and Petela, 1990). The steepest flue gas line that can be drawn against the existing process is also shown. The line corresponds to the smallest flue gas flowrate and smallest fuel consumption. "Trimming" the projecting part of the GRCC will allow a steeper flue gas line to be matched against the process. This is achieved by changing the stream flowrate which forms the projecting part of the curve. The steeper flue gas line results in reduced fuel consumption. The overall process duty remains unchanged.

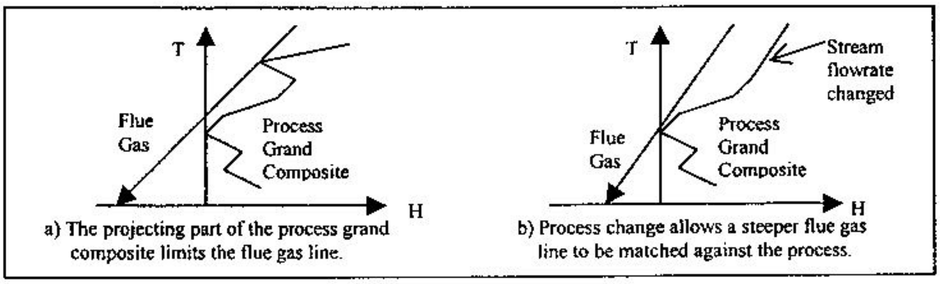


Figure 8 (a) and (b): The grand composite curves help identify opportunity for process changes.

RETROFIT TO MINIMIZE WASTE

The best way to treat waste is to avoid its formation at source. Minimising waste reduces the quantity of effluent generated, hence the investment and operating costs needed for treatment plants. Minimising waste also reduces the quantity of sludge to be disposed. Sludge formation is associated with most common types of effluent treatment methods, such as filtration, flocculation, chemical precipitation and even biological treatments.

Waste can be divided into two categories; process waste and utility waste (Smith and Petela, 1992). The former results from reactor and separator operations while the latter is attributed to heat exchanger networks and utility systems operations. In both areas, Pinch Technology can offer effective strategies for minimizing waste in an existing plant.

The strategies can be summarized as follows;

1. Minimising process waste by employing better start-up, shut-down and operating procedures; and optimisations of reactors and separators operations - increasing reactor conversion and product recovery.

2. Minimising utility waste through improvement of heat recovery systems, making appropriate changes to the process operating parameters and application of combined heat and power (cogeneration).

With process improvement and optimisation, the need for effluent treatment shall be reduced but *not eliminated.* Effluent treatment options may include filtration, extraction, adsorption, absorption, evaporation, membrane processes etc. In any case, the opportunity of re-utilizing energy recovered from the process for treatment purposes should always be explored. Pinch Analysis can help identify the part of a process that is most suitable as a heat source to the effluent treatment plant. This way, effluent treatment can be performed without additional energy cost.

CONCLUSIONS

It generally proves easy to identify measures to save energy in a process plant. Many improvements can be identified merely through simple energy balance calculations. However, a good many proposals may turn out to be unsuitable for implementation because of the following reasons;

1. The proposed project may have little practical value due to various process and plant limitations/constraints
2. The projected savings may prove "intangible" upon close monitoring
3. The bigger and more significant energy saving opportunities may have been missed

Plant improvements and optimizations should address the following issues in order to bring genuine benefits to a plant

1. A plant's potential/scope for improvement should be assessed during the early stages of retrofit. Plants' energy and retrofit targets are among the most useful performance indicators. Such guidelines are necessary in assessing the existing plant's performance.
2. Retrofit should consider the *overall process.* Identifying process sources and sinks can help pinpoint heat recovery losses and provide valuable insight for integration projects like CHP. It is crucial to begin retrofit at the "root of the problem" so that major opportunities are not missed. If possible, reactor and separators optimizations should be done before heat exchanger networks and utility systems.
3. Process and plant constraints should be scrutinized and clearly highlighted in the final proposal. Constraints for integration may include plant layout, operability, streams characteristics, equipment materials of construction, economics etc. Constraints for operational improvement include human factors, controllability, specific process limitations (e. g. corrosion limits), inevitable losses etc. Alternative measures should be proposed to overcome the constraints.
4. Estimate of project economy should be performed, and this should include at least the capital investment and the projected savings from the proposed measures. Cost of installing equipment, maintenance and labor should be duly incorporated. A conservative estimate should always be provided.

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